



WFIRST Science Definition Team and Project Final Report Presentation to HQ *

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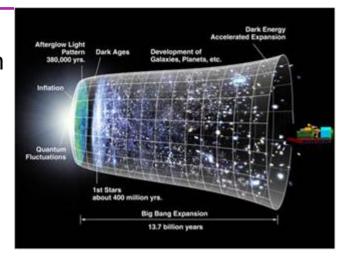
* These viewgraphs should not be read as a substitute for the full report.

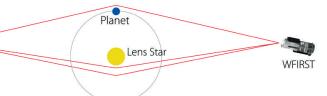


WFIRST Summary



- WFIRST is the highest ranked large space mission in NWNH, and plans to:
- complete the statistical census of Galactic planetary systems using microlensing
- determine the nature of the dark energy that is driving the current accelerating expansion of the universe
- survey the NIR sky for the community
- conduct a guest observer program
- ❖ Earth-Sun L2 orbit, 5 year lifetime, 10 year goal
- Measurements are
 - NIR sky surveys for BAO and weak lensing and
 - NIR monitoring for SNe and exoplanets
- Space-qualified large format HgCdTe detectors are US developed technology and flight ready









H4RG Mosaic Plate

H2RG EDU FPA



SDT original Charter



"The SDT is to provide science requirements, investigation approaches, key mission parameters, and any other scientific studies needed to support the definition of an optimized space mission concept satisfying the goals of the WFIRST mission as outlined by the Astro2010 Decadal Survey."

"In particular, the SDT report should present assessments about how best to proceed with the WFIRST mission, covering the cases that the Euclid mission, in its current or modified form, proceeds to flight development, or that ESA does not choose Euclid in the near future."



SDT Charter for Final Report



- December 7, 2011 Letter to SDT
 - 1. Finalize IDRM analysis started in 2011
 - Examine other options for reducing overall cost of mission
 - Launch capable by end of calendar year 2022
 - 2. Assess options to leverage off Euclid science
 - ☐ Develop a DRM that does not duplicate Euclid and LSST capabilities
 - Examine options for reducing overall cost of the mission
 - Launch capable by end of calendar year 2022
 - 3. SDT augmented with up to 6 new members
- March 1-2nd SDT Meeting
 - Additional direction from HQ to develop a DRM that does not duplicate the capability of JWST along with Euclid and LSST.



WFIRST Science Definition Team



Paul Schechter, MIT Co-Chair James Green, U. Colorado/CASA Co-Chair

Rachel Bean, Cornell University
Charles Baltay, Yale
David Bennett, Univ. of Notre Dame
Robert Brown, STScI
Christopher Conselice, Univ. of Nottingham
Megan Donahue, Michigan State Univ.
Scott Gaudi, Ohio State Univ.
Tod Lauer, NOAO
Bob Nichol, Univ. of Portsmouth

Saul Perlmutter, UC Berkeley / LBNL
Bernard Rauscher, GSFC
Jason Rhodes, JPL
Thomas Roellig, Ames
Daniel Stern, JPL
Takahashi Sumi, Nagoya Univ.
Angelle Tanner, Mississippi State Univ.
Yun Wang, Univ. of Oklahoma
Edward Wright, UCLA

Neil Gehrels, GSFC Ex-Officio Wes Traub, JPL Ex-Officio Rita Sambruna, NASA HQ Ex-Officio

New Members Jan. 2012

Xiaohui Fan, U. Arizona Chris Hirata, Caltech Jason Kalirai, STScl Nikhil Padmanabhan, Yale David Weinberg, Ohio State U.



H4RG-10 Mosaic Plate with WFIRST Science Definition Team, NASA HQ, and Project Office Team February 3, 2012







WFIRST – Science Objectives



- 1) Complete a statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs to all of the planets in our Solar System with the mass of Mars or greater.
- 2) Determine the expansion history of the Universe and its growth of structure in order to test explanations of its apparent accelerating expansion including Dark Energy and possible modifications to Einstein's gravity.
- 3) Produce a deep map of the sky at NIR wavelengths, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at z>10.
- 4) Provide a general observer program utilizing ≥10% of the mission minimum lifetime.



Euclid Context



The SDT was asked to consider the potential duplications of science capability between Euclid and WFIRST, (and LSST and JWST) and whether any cost savings could be realized by eliminating those duplications.



Euclid Context



The NRC Euclid report directly addressed this issue, independently of the SDT's efforts. It concluded:

"Euclid's and WFIRST's measurements are <u>not</u> <u>duplicative</u> (emphasis added) and the combinations will be more powerful than any single measurement. Combining WFIRST with Euclid and ground based data sets, such as that expected from LSST, should further enable astronomers to address the systematic challenges that previous ground-based weak lensing measurements have experienced. These combined data sets will likely overcome systematic limitations and realize the full potential of this powerful technique."



Euclid Context



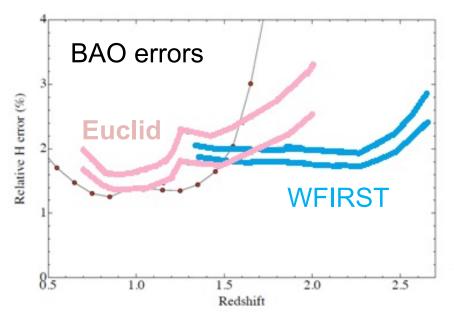
The SDT agrees with the assessment of the NRC report, but notes in addition that a flexible WFIRST that flies after Euclid should have the ability to optimize its science program in light of the results of Euclid and ground based efforts.



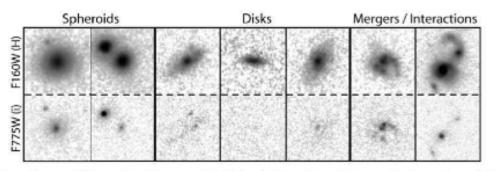
WFIRST – Euclid Comparison



Parameter	WFIRST	Euclid
Mirror diameter	1.5m (effective)	1.2m
Visible imager	none	36 CCD's
NIR imager spec	0.75x36 HgCdTe's	0.25x18 HgCdTe's
NIR pixel scale	0.18 " / pixel	0.30 " / pixel



Kocevski et al. http://www.arxiv.org/pdf/1109.2588



Wang & Bennett 2011



Design Reference Mission Options



- 1.3 meter off-axis telescope
- 3-channel payload
- 5 year mission
- Atlas V Launch Vehicle



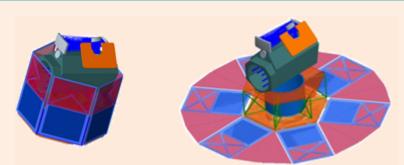
□ DRM1

- 1.3 meter off-axis telescope
- Single channel payload
- 5 year mission
- Atlas V Launch Vehicle



□ DRM2

- 1.1 meter off-axis telescope
- Single channel payload
- 3 year mission
- Falcon 9 Launch Vehicle





Key Hardware Changes



WFIRST DRM1, DRM2, vs. IDRM

■ New for DRM1:

- Single science channel, SpC SCA's moved to single larger focal plane array (FPA)
- Prism wheel for spectroscopy (Galaxy redshift survey & SN prism assemblies) at same 0.18" pixel scale as imaging
- Extension to 2.4um cutoff
- Gold mirror coatings

■ New for DRM2:

- H4RG-10 focal plane array
- Lightweight, compact design to fit on lower cost launch vehicle (Falcon 9)

☐ Unchanged:

- Unobstructed three mirror telescope
- Filter wheel after cold pupil
- Auxiliary guider used during spectroscopy observations

	,		
	IDRM	DRM1	DRM2
Focal plane array type	H2RG	H2RG	H4RG
FPA layout	ImC 7x4, SpC 2(2x2)	9 x4 H2RG	7x2 H4RG
Telescope aperture, m	1.3	1.3	1.1
Telescope temperature, K	220	205	205
	ImC 0.291, SpC		
Active field of view size, sq. deg.	2*0.26, total 0.81	0.375	0.585
	2 fixed opposed		
GRS implementation	prism channels	prism wheel	prism wheel
GRS bandpass, um	1.3-2.0	1.5-2.4	1.7-2.4
Focal length scales with pixel size, m	20.63	20.63	11.46
Optical axis relative to fairing axis	parallel	parallel	perpendicular
Spacecraft redundancy	full	full	selected
Sunshield type	fixed	fixed	deployable
Launch Vehicle	AtlasV	AtlasV	Falcon9
Mirror coatings	protected silver	gold	gold



DRM1 Exoplanet Survey Capability



In 500 days of total exoplanet microlensing survey time, WFIRST.

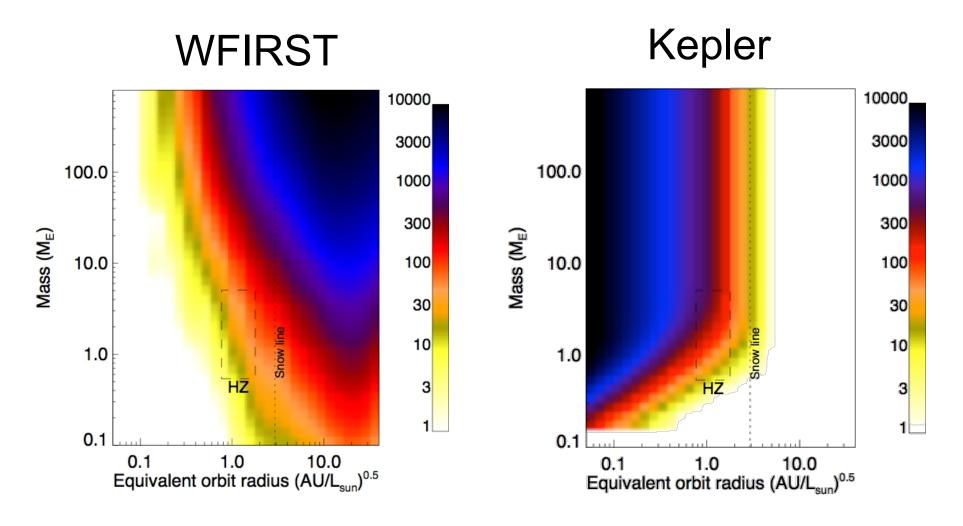
- Demographics beyond the snow line, where the planets form
- Detects >2000 bound exoplanets in 0.1 20,000 Earth mass (M_{Earth}) and 0.3 – 30 AU
- Detects ≥ 100 free floating planets* of 1 M_{Earth}
- Detects ≥ 250 terrestrial planets* (0.3 3 M_{Earth})

^{*} Assuming one such planet per star; "500 day surveys" are concurrent



WFIRST Exoplanet Parameter Space





Figures from B. MacIntosh of the ExoPlanet Task Force



Cosmic Acceleration History DRM1 Capabilities



- **BAO/RSD**: covers 3400 deg² to a limiting Hα flux of 1×10^{-16} ergs/cm²/sec (7σ) at resolution R = 600 over the redshift range 1.3 < z < 2.7.
- □ Weak Lensing: covers 3400 deg² to a limiting magnitude AB = 26 each in the Y, J, H and K filters yielding 30 galaxies/arcmin² in J, H and K.
- □ SNe-Ia: 2 tiered survey covering 6.5 deg² and 1.8 deg² with a five day cadence over 1.8 years yielding ~100 SNe per $\Delta z = 0.1$ bin for 0.4 < z < 1.7.



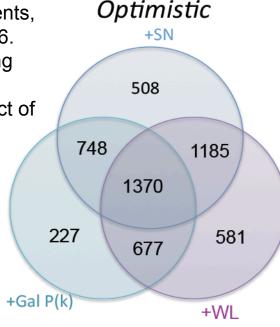
DETF Figure of Merit



Conservative

For this figure we adopt our conservative assumptions about SN and WL systematics, and we use only BAO information from the galaxy redshift survey. The FoM for all three probes combined is 682.

Forecasts of the DETF FoM for different combinations of the DRM1 WFIRST probes. All forecasts incorporate priors for Planck CMB and Stage III dark energy experiments, which on their own have an FoM of 116. Outer circles show the impact of adding WFIRST SN, WL, or BAO to these individually, and overlaps show the impact of adding combinations.



This figure is the corresponding diagram for the optimistic SN and WL systematics assumptions and the full P(k) analysis of the galaxy redshift survey. The FoM for each of the three methods improves, with a dramatic change in the case of WL, where the FoM nearly triples to 581. The combined FoM for the three methods is 1370, twice that of the conservative case.



DRM2 versus DRM1



□ DRM2 has only 60% of the observing time of DRM1. In the straw man allocations each program is reduced by this amount. ☐ extended sources: the figure of merit per unit time is the grasp – the field of view times collecting area. DRM2/DRM1 = 1.117. ☐ point sources: the figure of merit per unit time is the grasp divided by the diffraction limited solid angle. DRM2/DRM1 = 0.800 \square BAO/RSD: The redshift survey is restricted to 1.6 < z < 2.7 to compensate for the decreased observing time. ☐ Weak Lensing: DRM2 covers 2/3 the area of DRM1 with 25 resolved galaxies/deg² rather than 30. ☐ Exoplanet Microlensing: The shorter time baseline means that a smaller fraction of exoplanets will have measured masses rather than just mass ratios.



DRM 1 NIR Survey Capability



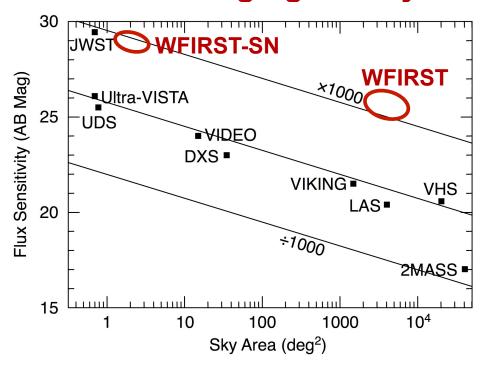
- Identify ≥ 2000 quasars at redshift z > 7 and ≥ 35 quasars at redshift > 10
- Obtain broad-band NIR spectral energy distributions of ≥ 3 X 10⁹ galaxies at z>1 to extend studies of galaxy formation and evolution
- Map the structure of the Galaxy using red giant clump stars as tracers



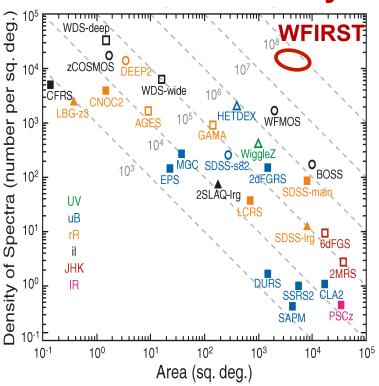
WFIRST NIR Surveys



NIR Imaging Surveys



NIR Redshift Surveys



WFIRST provides a factor of 100 improvement in IR surveys

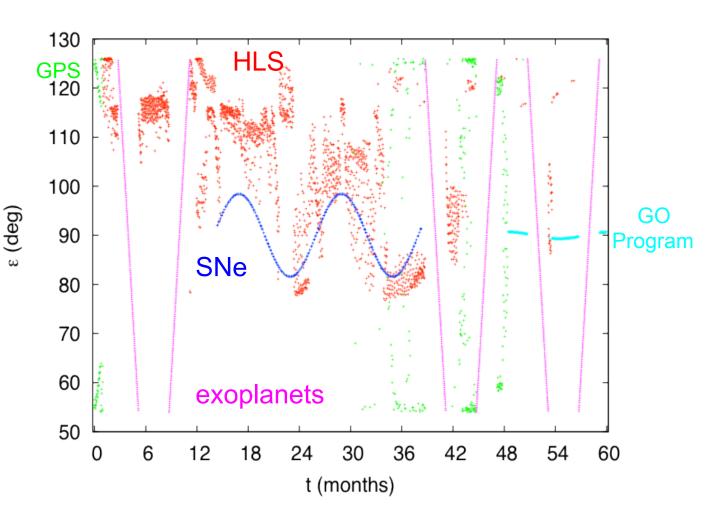


Survey Strategies



Example DRM1 Observing Plan

The horizontal axis shows time t from the start of observations, and the vertical axis shows the angle between the line of sight and the Sun (ϵ). The survey programs are color-coded: red for the HLS; green for the Galactic Plane survey; dark blue for the supernova survey; magenta for the microlensing survey; and light blue for the GO program





Straw Man Allocations



Program	DRM1	DRM2
exoplanet microlensing	14.4 months	8.9 months
general observer	6.1 months	3.6 months
supernovae	5.4 months	3.6 months
Galactic plane survey	5.3 months	3.4 months
high latitude imaging survey	14.6 months	9.9 months
redshift survey ^b	14.2 months	6.5 months
Totals	5.0 years	3.0 years

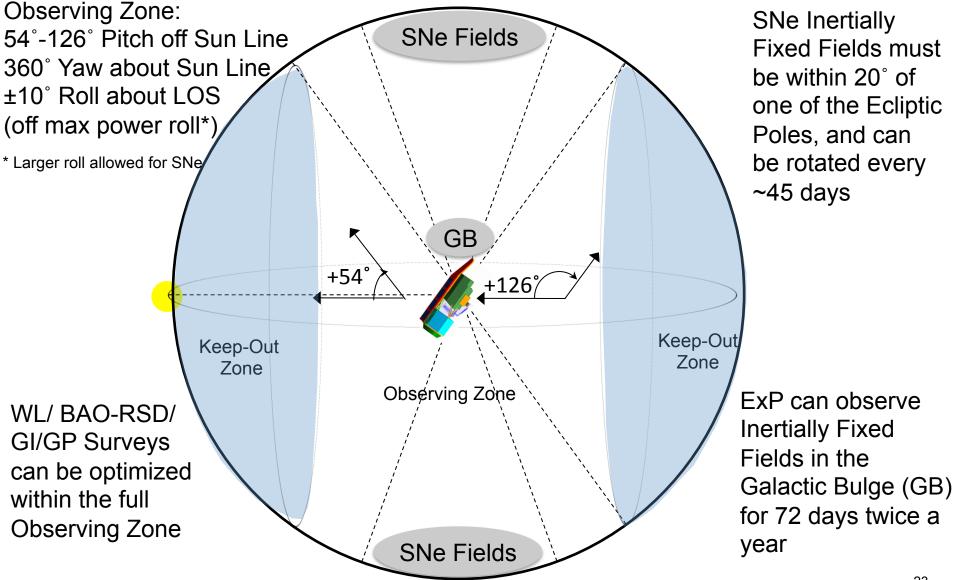
^a includes weak lensing survey

b includes baryon acoustic oscillation survey



WFIRST's Central Line of Sight (LOS) Field of Regard (FOR)





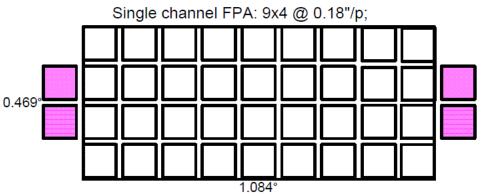


DRM1 Field of view & focal plane layout



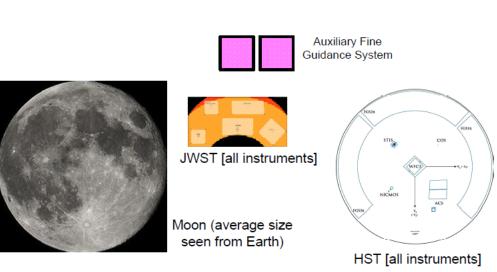
Channel field layout for WFIRST DRM1

1.3m uTMA, 9x4 single channel @0.18"/H2RG pixel
The Field of view of the single imaging &
spectroscopy channel is shown to scale with the
Moon, HST, and JWST. Each square is a 4Mpix
vis-NIR sensor chip assembly (SCA)



WFIRST-JWST Focal plane Comparison

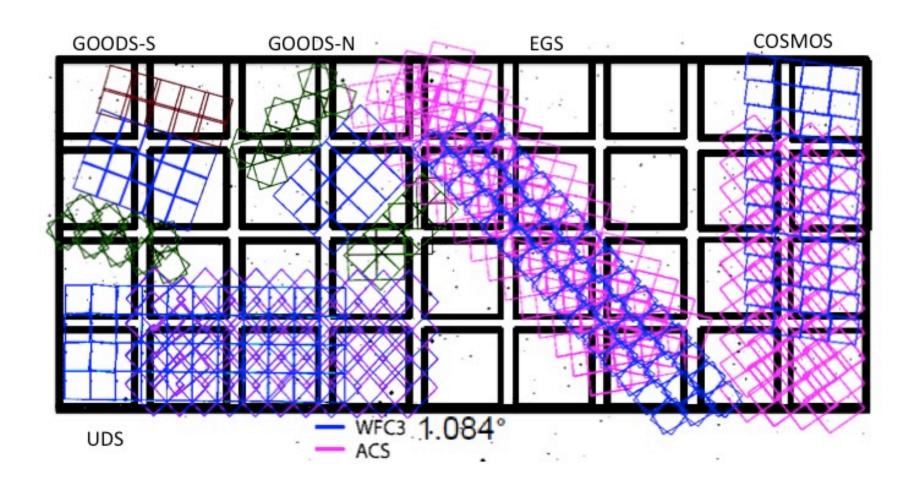
- Area is 145x larger than NIRCAM (0.375 vs. 0.00259 sq degrees
- Focal plane has 5x more pixels than NIRCAM short wave cameras (150 vs 33 Mpix)





CANDELS fields on DRM1 focal plane







DRM2 Field of view & focal plane layout



Channel field layout for WFIRST "DRM2"

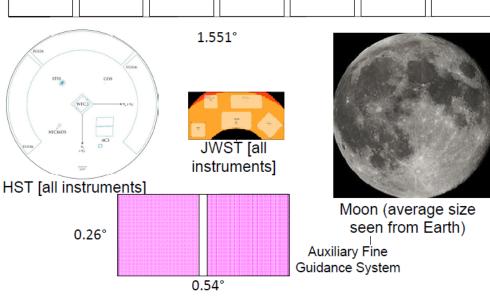
The Field of view of the single channel which can be used in imaging (Im), BAO spectroscopy (Sp), or SN spectroscopy (SNSp) mode is shown to scale with the Moon, HST, and JWST. Each square is a 16Mpix vis-NIR sensor chip assembly (SCA), 10 um pixels

7x2 @ 0.18"/p, 0.585 sq.deg

0.429°

WFIRST-JWST Focal plane Comparison

- Area is 226x larger than NIRCAM (0.585 sq vs 0.00259 degrees)
- Focal plane has 7x more pixels than NIRCAM short wave cameras (235 vs 33 Mpix)





DRM1 One Page Flow Down



- Substantiate that the DRM1 can achieve the science objectives mandated by NWNH.
- Trace WFIRST's Science Objectives to a set of derived Survey and Data Set requirements, and flow these down to a responsive Observatory Design and Ops Concept
- DRM1 is a Reference Design Multiple designs can meet the science requirements

Complete the statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs of all of planets in our Solar System with the mass of Mars or greate

Determine the expansion history of the Universe and its growth of structure so as to test explanations of its apparent accelerating expansion including Dark Energy and modifications to Einstein's gravity.

reionization epoch by finding bright quasars at z>10

Provide a quest observer program utilizing a minimum of 10% of the mission minimum lifetim

WFIRST Survey Capability Rqts

Exoplanet (ExP) Microlensing Survey Planet detection canability to ~0.1. Detects ≥ 125 planets of 1 M_m in 2

year orbits in a 500 day survey, with the masses of ≥ 90 of these planets being determined to better than 20%* Detects ≥ 25 habitable zone planets (0.5 to 10 M_@) in a 500 day survey * Detects ≥ 30 free floating planets of Ma in a 500 day survey

WEIRST Data Set Rate

Exoplanet Data Set Rgts Observe ≥ 2 square degrees in the Galactic Bulge at ≤ 15 minute sampling cadence S/N ≥100 for J-band magnitude ≤20

•≤0.3" imaging angular resolution Sample light curves with filter W166
 Monitor color with filter Y107, 1 exposure every 12 hours Minimum continuous monitoring tim span: ~60 days •Separation of ≥4 years between first and last observing seasons

Dark Energy Data Sets GRS Data Set Rqts

Slitless prism, spect. dispersion Rq 150 - 250 arcsec •S/N ≥7 for r_{eff} = 300 mas for Hα emission line flux at 2.0 μm ≥1.1x10

Dark Energy Surveys Galaxy Redshift Survey >3.000 deg2 sky coverag A comoving density of galaxy
 g z=2 of 2.9x10-4 Mpc⁻³ at 2 um Redshift range 1.3 ≤ z ≤ 2.7
 Redshift errors σ_z≤0.001(1+z), equivalent to 300 km/s rms Misidentified lines <5% persource

type, ≤10% overall; contamination fractions known to 2×10-3 Supernova SNe-la Survey •>100 SNe-la per Δz=0.1 bin for most bins for 0.4 < z < 1.2, per dedicated

distance modulus error σ_m ≤0.02 pe $\Delta z=0.1$ bin up to z=1.7Redshifterror σ ≤ 0.005 per

supernova • Relative instrumental bias ≤0.005 or photometric calibration across the wavelength range

WL Galaxy Shape Survey • ≥ 3,000 deg² sky coverage; effective galaxy density ≥30/amin², shapes resolved plus photo-z's

Additive shear error <3x10-4 Multiplicative shear err. ≤1x10⁻³
 Photo-z error distribution width ≤0.04(1+z),catastrophicerror rate

16 erg/cm²-s •Bandpass 1.5 ≤λ≤ 2.4 mm Pixel scale ≤ 180 mas
 System PSF EE50% radius 325 mas

3 dispersion directions required tw

nearly opposed •Reach J_{AB}=24.0 AND (H_{AB}=23.5 OR K_{AB}=23.1) for r_a=0.3 arcsec source at 10 sigma to achieve a zero order detection in 2 filters

Supernova Data Set Rqts

individual field: ~2 years with a sampling cadence ≤5 days • Cross filter color calibration ≤0.005 • Three filters, approximately J, H, K • Slitless prism spec (P130) 0.6-2 µm, $\lambda/\Delta\lambda$. ~75 (S/N \geq 2 per pixel bin) for redshift/typing •Photometric S/N≥15 at lightcurve

maximumin each band at each redshift

I ow Galactic dust F(B-V) < 0.02

WL Data Set Rqts From Space: 3 shape/color filter band (J,H, and K) and 1 color filter band (Y,

only for photo-z) S/N ≥18 (matched filter detection significance) pershape/colorfilterfor galaxy r_{eff} = 250 mas and mag AB =

galaxy r_{eff} = ∠50 mas and mag AB = 23.9 •PSF second moment (l_{xx} + l_{yy}) knowr to a relative error of ≤ 9.3x10-4 rms (shape/color filters only)

•PSF ellipticity (l_{xx}-l_{yy}, 2*l_{xy})/ (l_{xx} + l_{yy})

known to ≤ 4.7x10-4 rms (shape/color

filters only)

•System PSF EE50 radius ≤166 (J band), 185 (H), or 214 (K) mas At least 5 (H K) or 6 (J) random dithe required for shape/color bands, and 4 for Y at same dither exposure time From Ground: ≥4 color filter bands ~0.4 ≤ 1 ≤ ~0.92 µm •From Ground + Space combined:

Complete an unbiased spectroscopi PZCS training data set containing ≥ 100,000 galaxies ≤ mag AB = 23.9 (i JHK bands) and covering at least 4 uncorrelated fields; redshift accuracy required is σ_z<0.01(1+z)

Near Infrared Data Set Rqts

 Image ≥ 2500 deg² of high latitude sky in three near-infrared filters to minimum depths of mag AB = 25 at S/N=5 Fields must also have deer (ground-based) optical imaging • Image ≥ 1500 deg² of the Galactic

Key WFIRST DRM1 Observatory Design Parameters and

≤205 K telescope optical surfaces

•Bandpass 0.6 – 2.4 μm

 Coarse Pointing Accuracy <~3 arcsec rms/axis
 Fine (Relative/Revisit) Pointing Accuracy <~25 mas rms/axis *ACS telemetry downlinked for pointing history reconstruction
 Imaging Mode:

Punil Mask temperature: ~150 K

 Effective Area (avg over bandpass): 0.778 m²
 6 band parfocal filter set on wheel, driven by ExP, SNe, WL FPA: 4x9 HgCdTe 2k x 2k SCAs, 2.5mm, <100K, 180 mas/pix •FOV (active area) = ~0.375 deg²; Bandpass 0.6 – 2.4 μm •4 Outrigger FGS SCAs mounted to Focal Plane Assy (FPA) WFE is diffraction limited at 1 um

Spectroscopy Mode:

•SN Prism: R=75 (2-pix) parfocal, zero deviation prism

•SN Prism Effective Area (avg over bandpass): 0.750 m² (0.6 to

 2 oppositely dispersed GRS prisms: D_Q = 160 - 240 arcsec parfocal, zero deviation prism GRS Prism Effective Area (avg over bandpass: 0.953 m² (1.5

2.4μm) Aux FGS: 2 SCAs: controls Pitch/Yaw during spectro

1.156 - 1.520 0.920 - 2.400

Key WFIRST DRM1 Operations Concept Parameters

Science Field of Regard (FOR): 54° to 126° pitch off the Sun, 36 yaw •Roll±10°; SNe observations inertially fixed for ~45 days for

viewing near the ecliptic pole(s)
• Gimbaled antenna allows observing during downlinks
• Slew/settle times: ~16 s for dithers, ~38 s for ~0.7* slews SNe-la Survey (~11.7 deg²-yrs to z = 0.8, ~3.2 deg²-yrs to z

1.7)
•A sample 2-tiered survey capability (given ~6 months dedicated Tier1 (to z=0.8): 6.48 deg2; J134, H168, K211 (300 s @), P130

Tier 2 (to z=1.7): 1.80 deg² J134 H168 K211 (1500 s @) P13

 SNe dedicated time is distributed in a 5-day cadence over ~1.8 years to provide suitable light curve tracking and accurate hos galaxy references (e.g. if 6 months are dedicated SNe. 33 hrs o SNe field monitoring would be done every 5 days for ~1.8 years

• SNe fields are monitored from end of one ExP Galactic Bulge season until the start of the 4th following ExP season (~1.8 vrs) Fields located in low dust regions ≤20° off an ecliptic pole (N ar

4-9 sub-pixel dithers, accurate to ~15 mas, performed at each

ExP Survey (~2.62 deg² monitored every 15 min, 144 days/yr The Galactic Bulge is observable for two 72-day seasor

The short revisit cadence impacts other observing modes while exoplanet data sets are being acquired. This, in combination with the field monitoring time span required for SNe and the 60 days required for ExP, limits the max number of Galactic Bulge seasons useable for exoplanet observations to seven (over 5 yrs) In each season 7 fields are revisited on a 15 min cadence acquiring 88s exposures (filter W166) for light curve tracking except for one visit every 12 hours that uses filter Y107 for col Fields are revisited to an accuracy of 1 pixel rms; no precise

Galaxy Shape + Galaxy Redshift Survey (~1,400 deg²/yr) • Smooth-filled imaging in YJHK is obtained; exposure time in each iffler split over two roll angles (<u>Goal</u>) by -5' relative roll offset); shape measurements obtained in JHK -8 random dithers are acquired over the full field for YHK, 9

random dithers for J, providing 90% coverage at ≥5 exposure depth for YHK 6 for J

750 sec (150 sec per dither) integration time in each of YHK, 900

Near Infrared Survey Identify ≥100 quasars at redshift z ≥7

 Extend studies of galaxy formation and evolution to z > 1 by making sensitive, wide-field images of th extragalactic sky at near-infrared wavelengths, thereby obtaining broa band spectral energy distributions of ≥ 1x109 galaxies at z>1 Map the structure of the Galaxy using

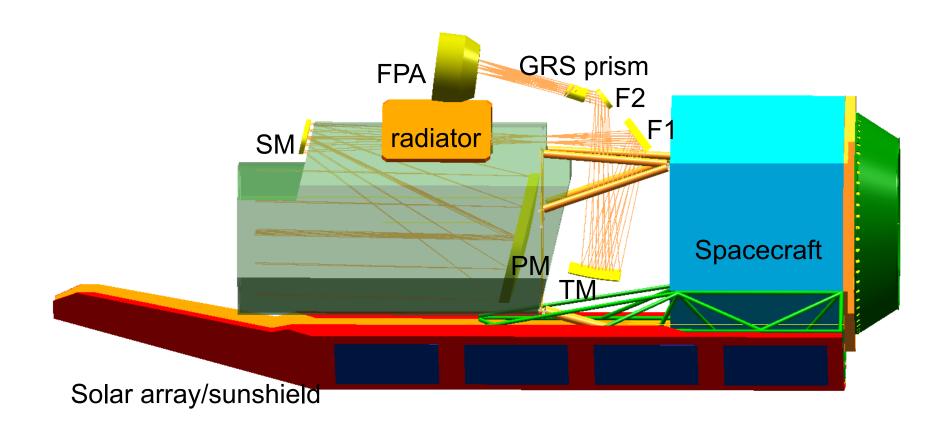
red giant clump stars as tracers

plane in three near-infrared filters



WFIRST DRM1 Observatory Layout & Ray Trace

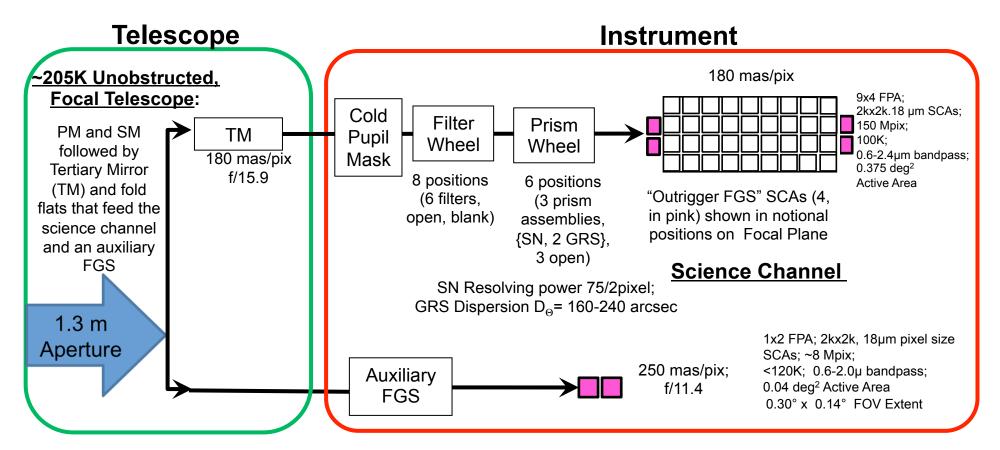






WFIRST DRM1 Payload Optics Block Diagram





GRS = Galaxy Redshift Survey

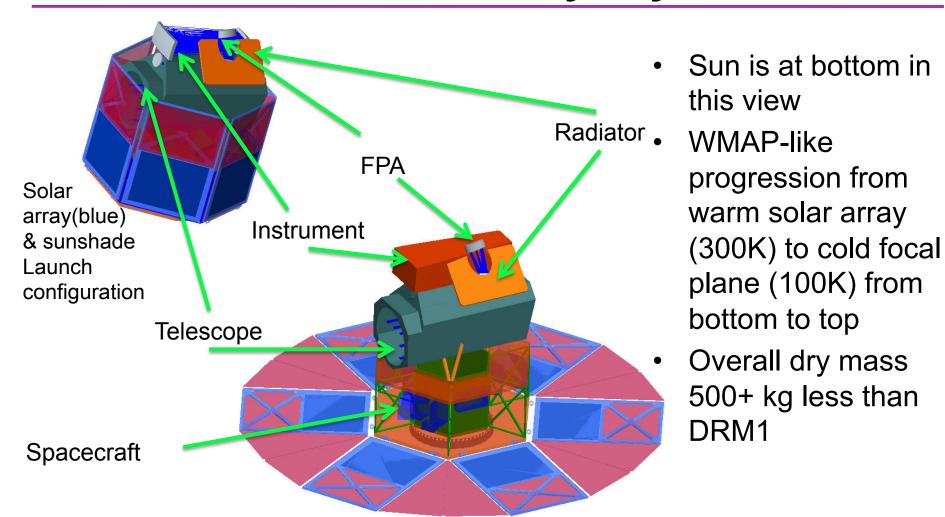
FGS = Fine Guidance Sensor: Outrigger FGS used during imaging, Auxiliary FGS used during spectroscopy

SN = Type1a Supernovae



WFIRST DRM2 Observatory Layout



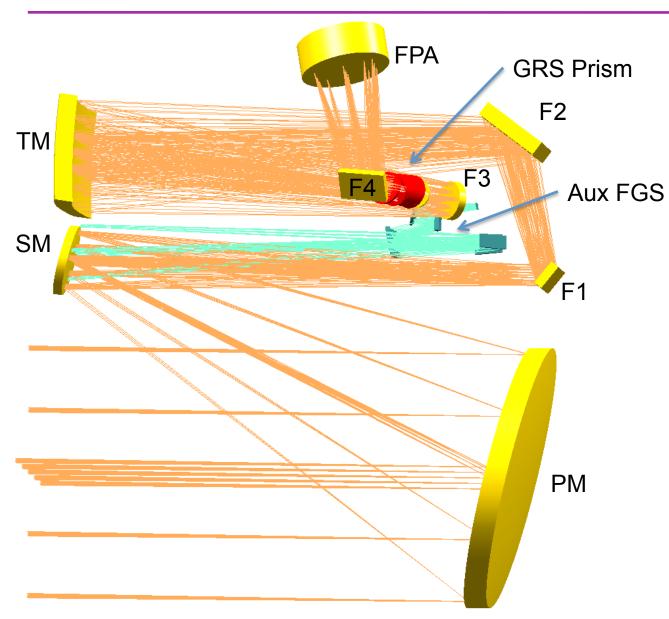


Solar array(blue) & sunshade, deployed



DRM2 – Ray Trace



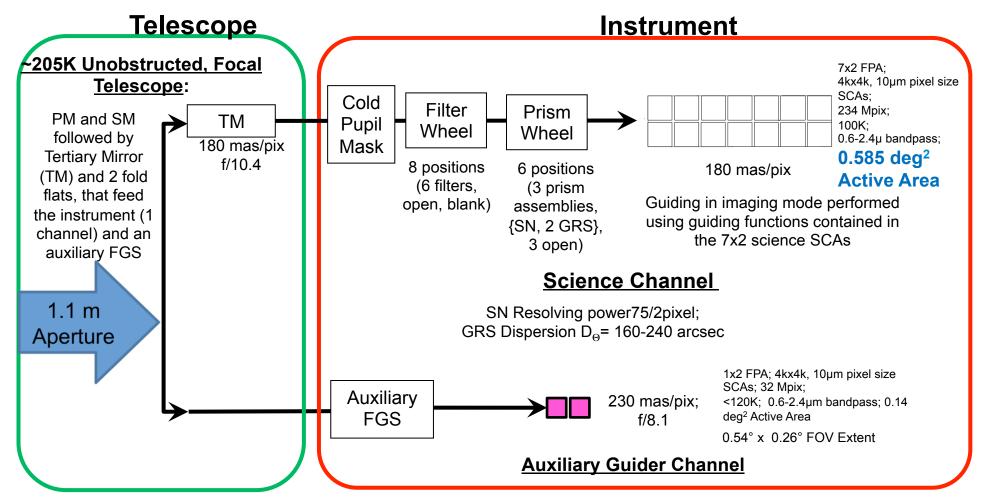


- Compact packaging has a lower cg which translates into lower mass
- Also enables deployable sunshade, horizontal optical axis
- Fits within lower cost launch vehicle even with mass margins required by CATE



WFIRST DRM2 Payload Optics Block Diagram





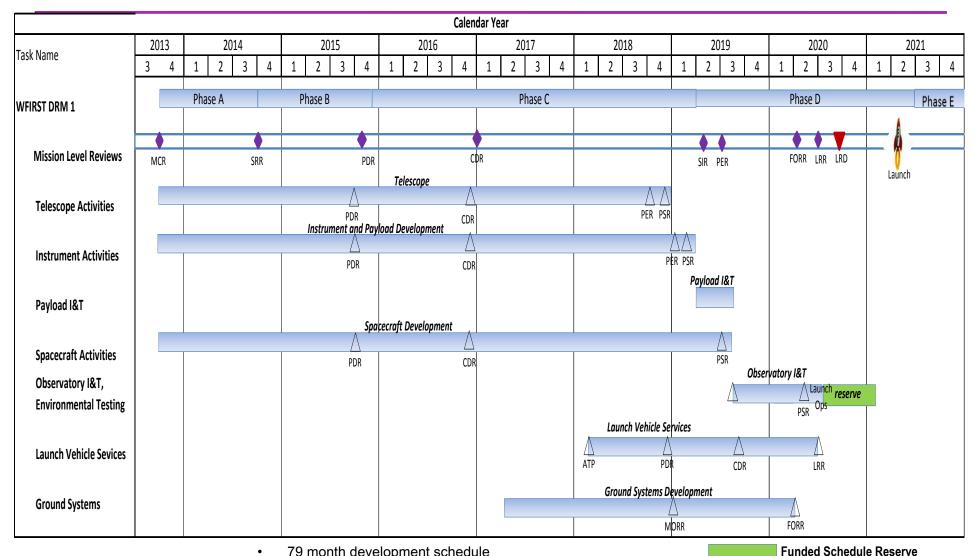
GRS = Galaxy Redshift Survey

FGS = Fine Guidance Sensor: Science SCA (guiding windows) used during imaging, Auxiliary FGS used during spectroscopy SN = Type1a Supernovae



WFIRST DRM1 Schedule Estimate





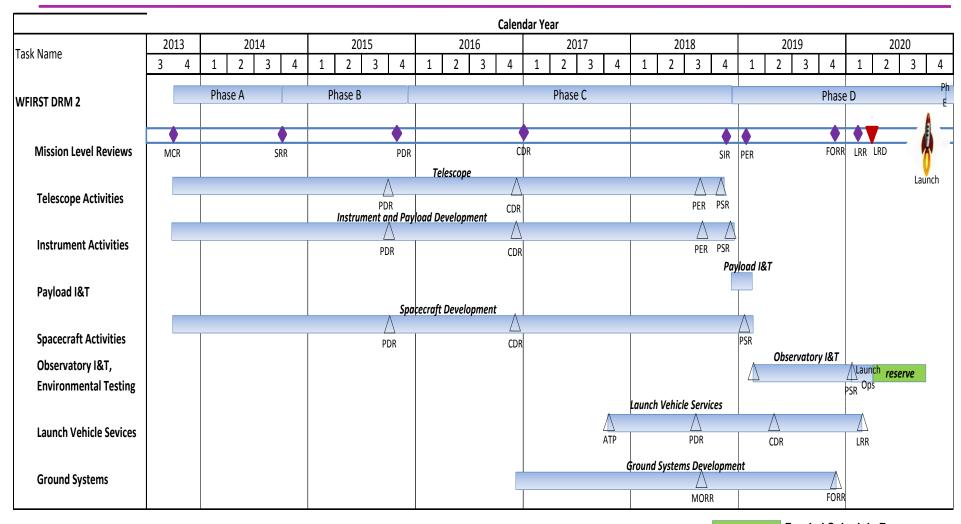
79 month development schedule

- Start of Phase B FY 15
- Launch Readiness Date Sept ember 2020
- 7 month schedule reserve



WFIRST DRM2 Schedule Estimate





• 72 month development schedule

- Start of Phase B FY 15
- Launch Readiness Date April 2020
- 6 month schedule reserve

Funded Schedule Reserve



WFIRST DRM1 Cost Estimate



- The IDRM life cycle cost estimate last year was \$1.63B. The ICE for the IDRM was 7% higher than the Project's estimate.
- The DRM1 configuration under study incorporates only one significant change vs. mid-2011 IDRM configuration.
 - Payload optical channels are reduced from 3 to 1.
- Assessment of the resulting cost savings from these changes indicates that the overall cost savings are modest - less than \$125M.

DRM1 (FY15 Start) - 1	.3m, single channel	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	TOTAL
DRM1 (FY15 Start)		Det. Dev	Phase A	Phase B		Phase	С		Phase	D		Phase E				Phases
		\Diamond	\Diamond		>	\Diamond		$\Diamond \Diamond$		\Diamond					\Diamond	A-E
(Schedule & Cost)		MCF	SRR,		R (CDR		NR SIR livery		Launch					EoM-P	
Pudget Pegits	Total RYM\$'s	\$13	\$26	\$139	\$113	\$116	\$423	\$362	\$218	\$147	\$55	\$57	\$58	\$60	\$41	\$1,816
Budget Req'ts	Total FY12M\$'s	\$13	\$25	\$129	\$102	\$102	\$362	\$302	\$177	\$116	\$43	\$43	\$43	\$43	\$29	\$1,515

- As a result of this, HQ has deferred performing the CATE on DRM1, given that the savings are modest and the CATE last year was in good agreement (7%) with the WFIRST Project's estimate.
- NOTE: based on the optimizations that have been studied on DRM2, should the desired path forward be a "DRM1-like" configuration, off-axis telescope with an aperture larger than 1.1 m, then our recommendation is that follow-on efforts examine the potential for extending the optimizations developed in the DRM2 configuration (more to follow).



WFIRST DRM2 Cost Estimate



- The DRM2 mission concept combines the cost efficiencies of the 2010 Probe mission concept with the payload simplicity and capability of the single channel DRM1.
- Significant mass reductions were enabled by rethinking major elements such as the solar array-sunshield, payload orientation, and spacecraft mechanical load path.
- Results in robust mass margins within capability of F-9 launch vehicle.
- The Project's estimate of the development cost of DRM2 (cost to clear the tower) is \$870M (\$FY12).
 - The comparable ICE development cost for the Probe in 2010 was approximately \$960M (\$FY12). The historical Probe ICE estimate has been adjusted to use the identical F-9 launch vehicle cost used in the DRM2 estimate to allow a comparison.

DRM2 (FY15 Start) - 1	.1m, single channel	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	TOTAL
DRM2 (FY15 Start)		Det. Dev	Phase A	Phase B		Phase	С		Phase D		Phase E			Phases
		\Diamond		<			\Diamond	$\Diamond \Diamond$		>		<	\Diamond	
(Schedule & Cost)		MCR SRR/ PD			R CDR SIR N				Laur	nch	EoM-P			
			MD	R			Delivery							
Budget Reg'ts	Total RYM\$'s	\$13	\$26	\$81	\$148	\$153	\$198	\$199	\$143	\$61	\$48	\$46	\$8	\$1,112
budget key is	Total FY12M\$'s	\$13	\$25	\$75	\$134	\$134	\$170	\$166	\$116	\$48	\$37	\$35	\$6	\$945

- The changes incorporated into the DRM2 configuration show promise for follow-on study.
- With more detailed engineering effort, the potential exists for exploiting some of the available margin to increase the telescope aperture and size of the focal plane, but staying within the low cost framework.
- Additional effort could also be applied to examine the cost benefit trade-off of additional redundancy in the spacecraft and instrument to enable potential extended operations of this low-cost WFIRST mission.
- DRM2 configuration <u>requires investment</u> in the H4RG detectors



Conclusion



- The SDT and Project have completed the action of developing two compelling mission concepts.
- DRM1: Fully responsive to the objectives of NWNH at reduced cost
- DRM2: Extraordinary low-cost near-infrared survey opportunity. The limited 3 year life precludes full compliance with NWNH goals.
- Recommended path forward:
 - The optimizations developed for DRM2 indicate that there is a scientifically compelling, medium-cost trade space, for developing a near infrared survey mission.
 - Refine the innovations developed in DRM2 into a "DRM1-like" mission concept; determine whether performance of this new concept can be fully responsive to NWNH.
- DRM1 and DRM2 are both compelling opportunities for wide-field nearinfrared surveys of critical importance to a broad spectrum of astronomical disciplines.
- Incorporating the optimizations that enabled DRM2 into DRM1 has the potential of creating an extraordinary opportunity to deliver the science required of NWNH at a medium class budget.